Mesabi-Select Concrete Pavement Five Year Performance Report

Minnesota Department of Transportation

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16. Abstract (Limit: 250 words)

Cell 54 was constructed in the fall of 2004 on the MnROAD low-volume loop. It is made up of eight inches of concrete underlain by Class 5 aggregate base and approximately three inches of compacted in-situ fill. Mn/DOT constructed this cell to study the properties of Mesabi-Select as coarse aggregate in concrete. This mineral aggregate that contains less iron than the ore, was obtained from overburdens in the iron ore ledges in northern Minnesota. There is no record of a previous cell constructed to study the suitability of Mesabi-Select in concrete.

Cell 54 is in very good condition after five years. There are very few cracks of low severity. The types of distress found were spalling of transverse joints, longitudinal cracking, and transverse cracking. Very little joint faulting has occurred. In-situ concrete surface permeability measurements indicate that the concrete is good quality. Friction and ride quality measurements indicate that Cell 54 is in very good condition. Falling weight deflectometer (FWD) deflections at the surface and top of the base were of similar magnitude as in other doweled jointed plain concrete pavement (JPCP) test cells of similar design.

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Executive Summary

A joint venture of Federal Highway Administration (FHWA), Minnesota Department of Transportation (Mn/DOT), Minnesota Department of Natural Resources (Mn/DNR), and the Minnesota Local Roads Research Board (LRRB) collaborated to build a test section labeled as Cell 54 in MnROAD Low Volume Road (LVR). It is made up of 8 in. of concrete underlain by Class 5 aggregate base and approximately 3 in. of compacted in-situ fill. Mn/DOT constructed Cell 54 to study properties of Mesabi-Select as coarse aggregate in concrete. This mineral aggregate, which contains lesser iron than the ore, was obtained from overburdens on the iron ore ledges in northern Minnesota. There is no record of a previous cell constructed to study the suitability of Mesabi-Select in concrete.

This project constructed a 192-ft, jointed-plain-dowelled concrete pavement comprising two lanes of 12- by 15-ft slabs paved by slip-form construction process on October 22, 2004. The longitudinal joints were tied and unsealed. Mn/DOT laboratory tested concrete samples for mechanical properties after rheological properties had been field evaluated.

The research objectives for the Cell 54 initiative included:

- To construct a concrete pavement with Mesabi-Select aggregate and investigate the material properties of the product placed.
- To investigate the rheological and mechanical properties of Mesabi-Select aggregate concrete.
- To study long-term performance of a concrete pavement in a low-volume road scenario built out of Mesabi-Select aggregate.
- To ascertain the susceptibility of the aggregate to synergistic effects in the presence of conventional admixtures.
- To investigate the adaptation of Mesabi-Select aggregate to traditional mix design variables, such as low water cement ratio, well-graded aggregates, and aggregate absorption.
- To construct an un-textured strip on the finished surface for a continuation of Mn/DOT's study of the effect of pavement texture and joints on ride quality.
- To provide a framework for the structural use of taconite aggregate in concrete.

The inside lane of Cell 54 has been loaded by the standard MnROAD 80-kip truck for over five years. Performance data was continuously obtained from embedded strain gauges, vibrating wires, moisture sensors, and thermocouples. After five years:

- Surface Distress: there are very few cracks of low severity. The types of distress found were spalling of transverse joints, longitudinal cracking, and transverse cracking. Very little joint faulting has occurred.
- Permeability: in-situ concrete surface permeability measurements indicate that the concrete is good quality.
- Friction: friction number with a smooth tire ranged from 29.1 to 42.5 and with a ribbed tire from 51.2 to 63.5.
- IRI: varies from 79.4 to 91.3 in/mi.

- The joint closure temperature, measured by vibrating wire strain gauges, was lower than that in other concrete test cells of similar design and thickness at MnROAD.
- FWD deflections at the surface and top of the base were of similar magnitude as in other doweled JPCP test cells of similar design.

1 Introduction

1.1 Background

The Minnesota Department of Transportation (Mn/DOT) constructed the Minnesota Road Research Project (MnROAD) between 1990 and 1994. MnROAD is located along Interstate 94 forty miles northwest of Minneapolis/St. Paul and is an extensive pavement research facility consisting of two separate roadway segments containing dozens of distinct test cells. Each MnROAD test cell is approximately 500 feet long. Subgrade, aggregate base, and surface materials, as well as roadbed structure and drainage methods vary from cell to cell. All data presented herein, as well as historical sampling, testing, and construction information, can be found in the MnROAD database and in various publications. Layout and designs used for the Mainline and Low Volume Road are shown in Appendix A. Additional information on MnROAD can also be found on its web site at http://www.dot.state.mn.us/mnroad.

Parallel and adjacent to Interstate 94 and the Mainline is the Low Volume Road (LVR). The LVR is a 2-lane, 2½-mile closed loop that contains over 20 test cells. Traffic on the LVR is restricted to a MnROAD operated vehicle, which is an 18-wheel, 5-axle, tractor/trailer with two different loading configurations. The "heavy" load configuration results in a gross vehicle weight of 102 kips (102K configuration). The "legal" load configuration has a gross vehicle weight of 80 kips (80K configuration). On Wednesdays, the tractor/trailer operates in the 102K configuration and travels in the outside lane of the LVR loop. The tractor/trailer travels on the inside lane of the LVR loop in the 80K configuration on all other weekdays. This results in a similar number of ESALs being delivered to both lanes. ESALs on the LVR are determined by the number of laps (80 per day on average) for each day and are entered into the MnROAD database. Beginning in the winter of 2008, the MnROAD truck operated only in the 80K configuration and only on the inside lane of the LVR loop. The outside lane is left unloaded to study environmental effects.

The mainline consists of a 3.5-mile 2-lane interstate roadway carrying "live" traffic. The Mainline consists of both 5-year and 10-year pavement designs. The 5-year cells were completed in 1992 and the 10-year cells were completed in 1993. Originally, a total of 23 cells were constructed consisting of 14 HMA cells and 9 Portland Cement Concrete (PCC) test cells. Phase 2 reconstruction during the construction season of 2008 involved the reconstruction of more than 35 new test cells. Detailed information about the original and new test cells can be found in Appendix A.

Traffic on the mainline comes from the traveling public on westbound I-94. Typically the mainline traffic is switched to the old I-94 westbound lanes once a month for three days to allow MnROAD researchers to safely collect data. The mainline ESALs are determined from an IRD hydraulic load scale that was installed in 1989 and a Kistler quartz sensor installed in 2000. Currently the mainline has received roughly 5 million flexible Equivalent Single Axle Loads (ESALs) and 7.8 million Rigid ESALS as of December 31, 2004.

1.2 MnROAD Instrumentation and Performance Database

Data collection at MnROAD is accomplished with a variety of methods to help describe the layers, the pavement response to loads and the environment, and actual pavement performance. Layer data is collected from a number of different types of sensors located throughout the pavement surface and sub-layers, which initially numbered 4,572. Since then we have added to this total with additional installations and sensors types. Data flows from these sensors to several roadside cabinets, which are connected by a fiber optic network that is feed into the MnROAD database for storage and analysis. Data can be requested from the MnROAD database for each sensor along with the performance data that is collected thought the year. This includes ride, distress, rutting, faulting, friction, and forensic trenches. Material laboratory testing and the sensors measure variables such as temperature, moisture, strain, deflection, and frost depth in the pavement along with much more.

1.3 Research Objectives

Northern Minnesota has abundant deposits of iron ore. These deposits are either harnessed for ore extraction or are removed as overburdens if the rock contains lesser iron content. In either case, piles of available aggregate are the byproduct of the mining activities. Extraction of iron from the ore has resulted in-stockpiles of taconite tailings. These tailings, labeled Mesabi Select when used as construction aggregates, are believed to be of some use as aggregate. Test Cell 54 was therefore built with concrete that has Mesabi-Select as the only coarse aggregate.

The research objectives for the Cell 54 initiative included:

- To construct a concrete pavement with Mesabi-Select aggregate and investigate the material properties of the product placed.
- To investigate the rheological and mechanical properties of Mesabi-Select aggregate concrete.
- To study long-term performance of a concrete pavement in a low-volume road scenario built out of Mesabi-Select aggregate.
- To ascertain the susceptibility of the aggregate to synergistic effects in the presence of conventional admixtures.
- To investigate the adaptation of Mesabi-Select aggregate to traditional mix design variables, such as low water cement ratio, well-graded aggregate, and aggregate absorption.
- To construct an un-textured strip on the finished surface for a continuation of Mn/DOT's study of the effect of pavement texture and joints on ride quality.
- To provide a framework for the structural use of taconite aggregate in concrete.

This project constructed a 192-ft jointed-plain-dowelled concrete pavement comprising two lanes of 12- by 15-ft slabs paved by slip-form construction process. The longitudinal joints were tied and unsealed.

2 Five Year Performance

The previous chapter introduced the MnROAD test facility and the research objectives of test Cell 54. This chapter discusses the performance of Cell 54 after five years. Performance was measured through surface distress, transverse joint faulting, concrete surface permeability, friction testing, ride quality, and falling weight deflectometer (FWD) deflections.

2.1 Surface Distress

Distress surveys were performed at regular intervals to monitor the field performance of test Cell 54. The data collected included the distress type, extent or amount of distress, and the severity of the distress. The test cell was surveyed for spalling of the transverse and longitudinal joints, transverse and longitudinal cracking, cracked panels, broken panels, faulted panels, patched panels, and D-cracking.

Cell 54 is in very good condition after five years. There are very few cracks of low severity. The types of cracking found were spalling of transverse joints, longitudinal cracking, and transverse cracking. The severity levels for these distress types are defined as:

Spalling of Transverse Joints

- **Low –** Less than 3” wide spalls
- **Moderate –** 3” to 6” wide spalls
- **High –** Greater than 6” wide spalls

Longitudinal Cracking

- **Low –** Well sealed or hairline cracks with no spalling or faulting
- **Moderate –** Cracks with low or moderate severity spalling; faulting less than ½”; crack widths ½” or less
- **High –** Cracks with high severity spalling; faulting ½” or more; crack widths greater than ½”

Transverse Cracking

- **Low –** Hairline cracks with no spalling or faulting
- **Moderate –** Cracks with low severity spalling; faulting less than ¼”; crack widths ½” or less
- **High –** Cracks with moderate or high severity spalling; faulting ¼” or more; crack width greater than ½”

2.2 Joint Faulting

A modified version of the Georgia Faultmeter is used to measure transverse joint faulting. Faulting is measured in the wheel path at three and ten foot offsets from the centerline. Cell 54 was a 7.5 inch thick JPCP with 15 ft long and 12 ft wide panels with 1 inch diameter dowels spaced at 12 inches. For a doweled pavement of this thickness, there should be very little joint faulting after five years. As shown in Table 2, joint faulting ranged from 0.00 to 0.70 mm with the average joint faulting 0.24 mm.

TABLE 1 Transverse Joint Faulting

Cell No.	Lane	Wheel Path	Date	Joint No.	Fault Depth (mm)
54	Inside	Right	6/18/09	1279	0.20
54	Inside	Right	6/18/09	1280	0.40
54	Inside	Right	6/18/09	1277	0.50
54	Inside	Right	6/18/09	1285	0.70
54	Inside	Left	6/18/09	1285	0.00
54	Inside	Left	6/18/09	1279	0.00
54	Inside	Left	6/18/09	1277	0.30
54	Inside	Left	6/18/09	1280	0.40

TABLE 2 Surface Distress

		Survey Date								
		5/19/05	**10/13/05**	**4/20/06**	**10/30/06**	**4/13/07**	**11/7/07**	**4/2/08**	**6/24/09**	**9/17/09**
Inside Lane	Longitudinal Crack Low Severity No.	0	0	0	0	0	0	0	1	2
	Longitudinal Crack Low Severity Length (ft)	0	0	0	0	0	0	0	5	8
	Transverse Crack Low Severity No.	0	0	0	0	0	0	0	1	1
	Transverse Crack Low Severity Length (ft)	0	0	0	0	0	0	0	12	12
	Transverse Spalling Low Severity No.	0	0	0	0	0	0	0	1	1
	Transverse Spalling Low Severity Length (ft)	0	0	0	0	0	0	0	4	2
Outside Lane	Longitudinal Crack Low Severity No.	0	0	0	0	0	0	0	0	0
	Longitudinal Crack Low Severity Length (ft)	0	0	0	0	0	0	0	0	0
	Transverse Crack Low Severity No.	0	0	0	0	0	0	0	0	0
	Transverse Crack Low Severity Length (ft)	0	0	0	0	0	0	0	0	0
	Transverse Spalling Low Severity No.	0	0	0	0	0	0	0	1	1
	Transverse Spalling Low Severity Length (ft)	0	0	0	0	0	0	0	4	2

2.3 Concrete Permeability

The Proceq permeability tester was used to measure the in-situ permeability of the concrete. The device has a probe with two chambers; inner and outer. A vacuum is created between the concrete surface and the two chamber probe. The two chambers insure that in the inner chamber, the air is moving through the concrete perpendicular to the surface, similar to how a double ring infiltrometer works. After establishing the vacuum, it is removed and the change in pressure over 12 minutes is measured, the smaller the change in pressure, the lower the permeability. The WENNER probe is used with the Proceq permeability tester to measure concrete resistivity. This information along with the permeability can be used to find the quality of the cover concrete. Measurements taken on April 8, 2009 indicate that the surface concrete on Cell 54 is in good or very good condition.

TABLE 3 Permeability Measurements

Lane	Panel No.	Resistivity (k-Ohms)	Permeability $1x10^{-16}$ m^2	Concrete Quality
Outside	3	21	0.024	Good
Outside	4	21	0.052	Good
Outside	9	31	0.086	Good
Outside	10	36	0.001	Very Good

2.4 Friction Testing

Friction was measured by the KJ Law skid trailer and grip tester. The KJ Law skid trailer was used annually and the grip tester was used for the first time in 2009.

2.4.1 KJ Law Skid Trailer

Pavement friction was measured using the KJ Law (Dynatest) skid trailer. Pavement surface friction is regarded as an indicator of safety for vehicles on highways because it is a measure of the force that resists sliding of vehicle tires on a pavement. Friction resistance is the force developed when a tire that is prevented from rotating slides along the surface of the pavement. Although friction resistance is often thought of as a pavement property, it is actually a property of both the pavement surface characteristics and the vehicle tires. The Friction Number testing process involves application of water to the pavement surface prior to determination of the friction value. The skid number (SN) is calculated as the average coefficient of friction across the test interval. Skid Numbers could theoretically range from 0 to 100. As a general rule, a SN above 25 on a smooth tire gives adequate friction, and a SN below 15 needs remediation. Likewise, a SN above 40 on a ribbed tire gives adequate friction, and a SN below 25 needs remediation.

Friction measurements were made annually starting in the summer of 2005. As shown in Table 4, friction measurements made with a smooth tire started at 42.5 in 2005 and decreased to 29.1 in 2009. Friction measurements made with a ribbed tire started at 58.6 in 2005 and decreased to 52.2 in 2009.

TABLE 4 Friction Testing

Date	Time	Lane	Air Temp [F]	Pavement Temp [F]	Tire Type	SN	Peak	Speed
6/13/05	13:31	Outside	-	97	Ribbed	58.6	90.4	38.9
6/13/05	13:37	Outside	-	98.8	Smooth	42.5	65.3	38.7
6/14/06	11:00	Inside	87	-	Smooth	42.1	66.86	41.4
6/14/06	11:16	Outside	86	-	Ribbed	61.9	93.29	40.6
11/6/07	11:30	Inside	37	47.1	Ribbed	63.5	97.42	38.7
10/31/08	9:15	Outside	68	59.8	Ribbed	55.7	89.1	39.6
10/31/08	9:28	Inside	68	59.6	Smooth	36.2	49.2	40.1
10/31/08	9:40	Inside	68	58.6	Ribbed	51.2	83.4	38.9
6/4/09	10:17	Inside	68	96.8	Ribbed	58.4	85.5	39.4
6/4/09	10:25	Inside	68	94.3	Smooth	29.1	34.7	41.9
6/4/09	10:50	Outside	68	98.3	Ribbed	52.2	85.4	40.6
6/4/09	11:00	Outside	68	96.5	Smooth	42	63.9	40.5

2.4.2 Grip Tester

The Grip Tester is a braked wheel, fixed slip device with drag and load (horizontal and vertical force) continuously monitored and their quotient (coefficient of friction) calculated and displayed. A grip number of 0.0 is frictionless with friction increasing up to a maximum grip number of 1.0. Figure 1 shows grip test results taken on April 24, 2009 on the inside lane (trafficked lane) right wheel path. The results from four different test runs are shown in the figure. Since there is not an automated trigger to start and stop testing, the test results may be slightly offset from each other. Additional grip tester results are in Appendix B.

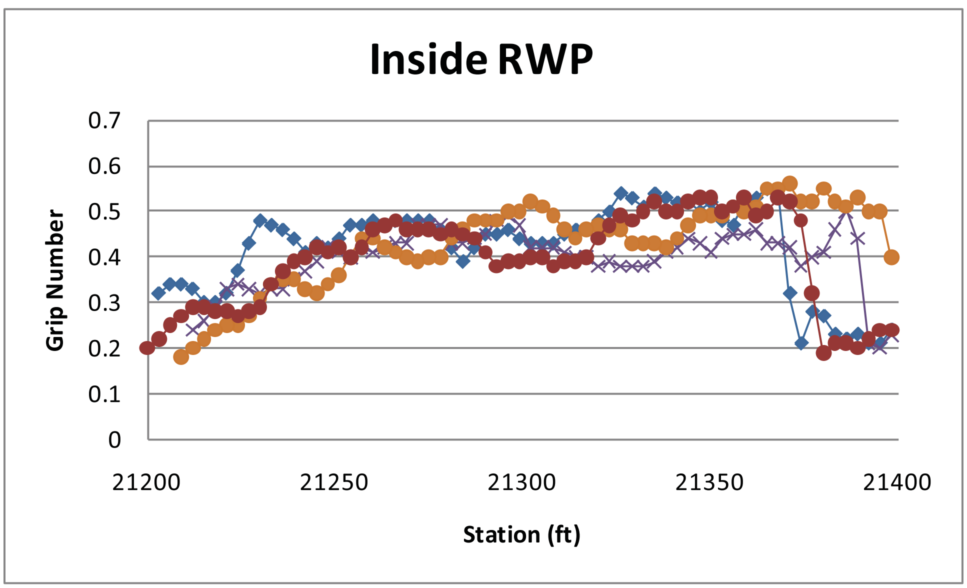

FIGURE 1 Inside lane right wheel path grip number.

2.5 Ride Quality

At MnROAD, a Lightweight Inertial Surface Analyzer (LISA) profiler mounted on a utility vehicle is used to measure ride quality in term of International Roughness Index (IRI). Ride quality is typically measured three times per year, although it was not measured on Cell 54 until the spring of 2009. The typical design terminal Present Serviceability Rating (PSR) for Mn/DOT pavements is 2.5, which corresponds to an IRI of 150 in/mile. Cell 54 was tested for IRI on April 2, 2009. As shown in Table 5, IRI is still very good in Cell 54.

TABLE 5 Ride Quality

Lane	Wheel Path	IRI (in/mi)
Outside	Left	79.4
Outside	Left	82.0
Outside	Right	91.3
Outside	Right	86.8
Inside	Left	81.1
Inside	Left	83.6
Inside	Right	86.0
Inside	Right	89.9

2.6 Falling Weight Deflectometer Deflections

The primary objective of this research project was to determine if the Mesabi Select coarse aggregate had the durability to resist chemical attack and freeze-thaw cycles. Falling Weight Deflectometer (FWD) deflections can be used to determine if the concrete pavement has lost some of its strength. Table 6 shows the deflections in Cell 54 and two other doweled JPCP test cells of similar thickness with similar base layers, Cells 52 and 38. Test cell 54 is a 7.5 in. thick JPCP with 1.0 in. dowels and 15 x 12 ft panels. It has a 12 in. thick Class 6 base and clay subgrade. Test cell 52 is a 7.5 in. thick JPCP with 1.0 in. dowels and 15 x 14 ft panels. It has a 5 in. thick Class 4 base and clay subgrade. Test cell 38 is a 6.5 in. thick JPCP with 1.0 in. dowels and 15 x 12 ft panels. It has a 5 in. thick Class 5 base and clay subgrade.

As shown in Table 6 and 7, the deflections in Cell 54 are very similar to the deflections in the other two cells. This indicates that Cell 54 has not lost strength as measured by FWD. Figures 2, 3, and 4 shows center panel FWD deflection basins for test Cells 54, 52, and 38. The deflections of Cells 54 and 52 are of similar magnitude but the deflections for Cell 38 are higher. This is most likely because Cell 38 is one in. thinner than Cells 54 and 52.

TABLE 6 Falling Weight Deflectometer Deflections at Surface

	Drop Weight (lbs)	Center Panel Deflection (mils)	Corner Panel Deflection (mils)	Mid Edge Deflection (mils)
Cell 54 May 5, 2005	**6000**	2.9	4.8	7.2
	9000	4.4	7.5	10.8
	12000	6.1	10.5	14.2
Cell 54 October 26, 2009	**6000**	3.1	13.6	8.2
	9000	4.5	18.0	11.4
	12000	5.9	22.0	14.5
Cell 52 October 26, 2009	**6000**	3.4	12.4	8.2
	9000	5.0	18.8	12.2
	12000	6.8	24.7	16.4
Cell 38 October 27, 2009	**6000**	6.2	11.2	12.0
	9000	9.0	16.6	17.6
	12000	11.8	22.6	23.8

TABLE 7 Falling Weight Deflectometer Deflections at Top of Base

	Drop Weight (lbs)	Center Panel Deflection (mils)	Corner Panel Deflection (mils)	Mid Edge Deflection (mils)
Cell 54 May 5, 2005	**6000**	2.7	4.6	6.6
	9000	4.2	7.0	10.0
	12000	5.7	10.0	13.1
Cell 54 October 26, 2009	**6000**	2.9	12.1	7.8
	9000	4.2	16.1	11.1
	12000	5.5	19.7	14.0
Cell 52 October 26, 2009	**6000**	3.2	10.9	7.9
	9000	4.8	16.2	11.7
	12000	6.4	21.9	16.0
Cell 38 October 27, 2009	**6000**	5.9	10.2	11.1
	9000	8.6	15.3	16.5
	12000	11.3	20.8	22.3

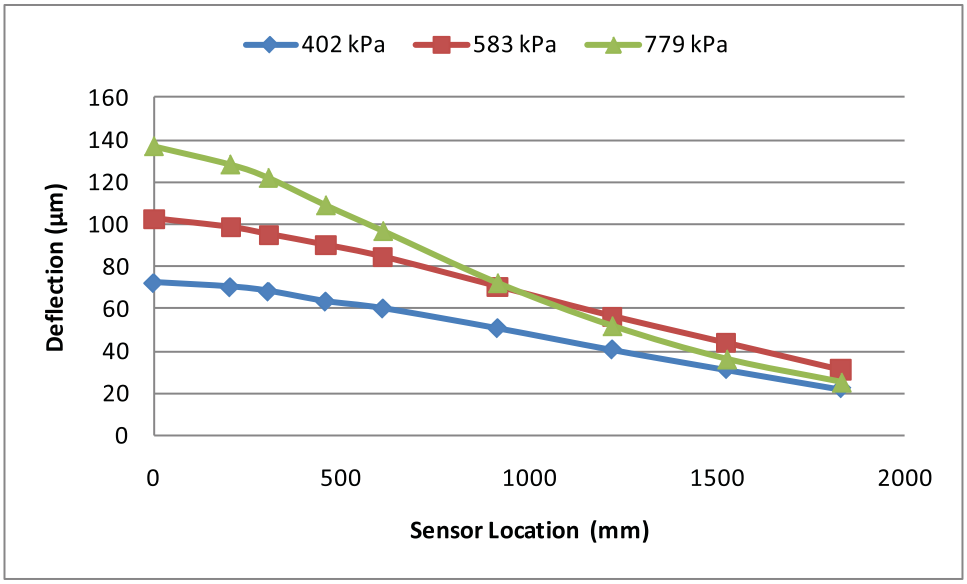

FIGURE 2 Cell 54 FWD deflection basins.

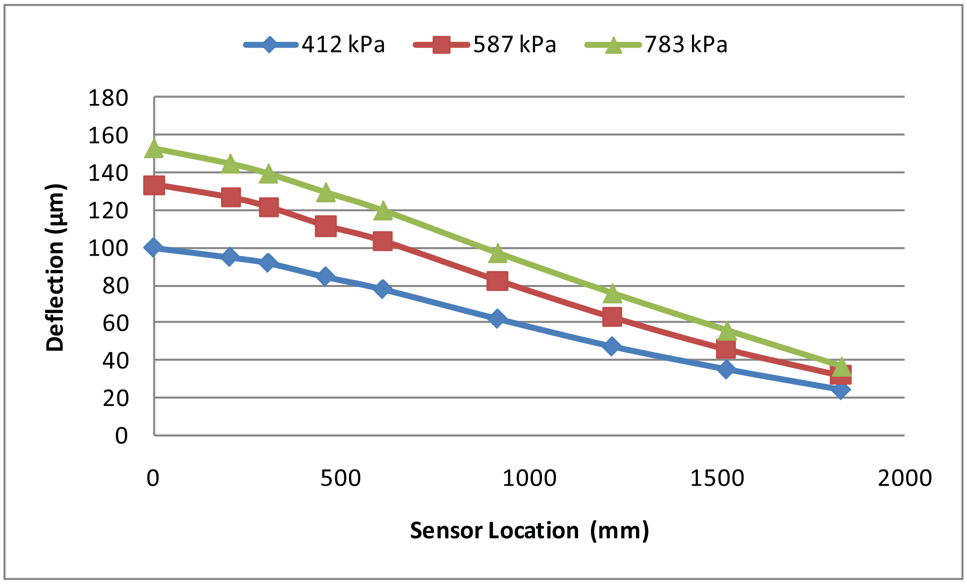

FIGURE 3 Cell 52 FWD deflection basins.

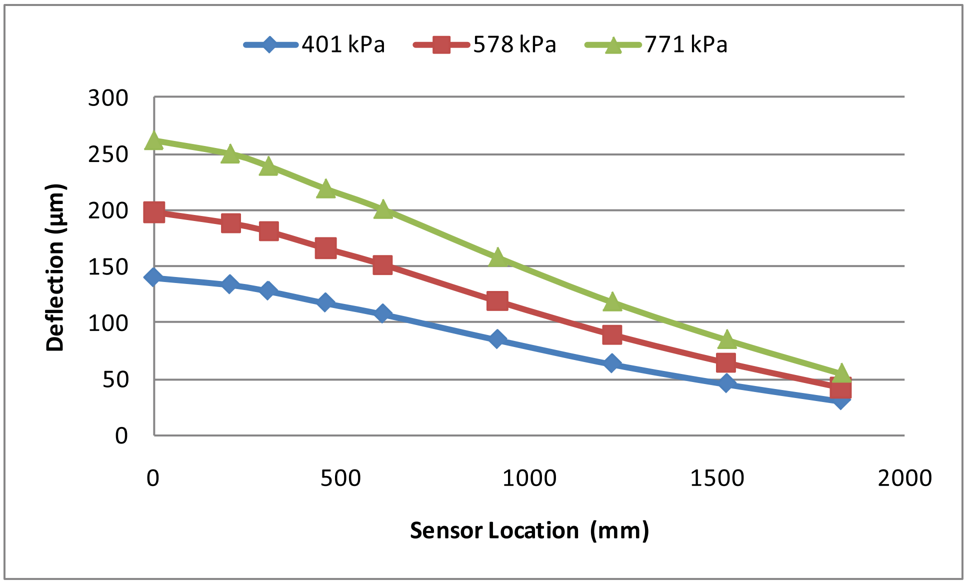

FIGURE 4 Cell 38 FWD deflection basins.

3 Strain Response

This chapter discusses the drying shrinkage and joint closure temperatures of Cell 54. Since the behavior of Mesabi Select Aggregates is under investigation, comparing the shrinkage and joint closure temperatures to standard concrete mixes is of interest.

3.1 Shrinkage

The total strain was calculated from the vibrating wire (VW) strain data from:

$$\boldsymbol{\varepsilon_{total}} = (\boldsymbol{R_1} - \boldsymbol{R_0}) + \left((\boldsymbol{T_1} - \boldsymbol{T_0}) * \boldsymbol{CF_{st}}\right) \quad \textbf{[1]}$$

where:

ε_{total}: total strain
R_0: initial strain value (immediately after paving)
R_1: measured strain value at time T_1
T_0: initial temperature value (immediately after paving)
T_1: measured temperature value at time T_1
CF_{st}: coefficient of thermal expansion for VW sensor

The second half of Equation 1 is used to correct the sensor reading for the difference between the thermal expansion of the steel vibrating wire sensor and the concrete. Since the VW sensors were not collecting data when the test cell was paved, the earliest values collected were used for the initial strain value (R_0) and the initial temperature value (T_0). The temperature values were not the air temperature, instead it was the temperature of the concrete at the location of the VW sensor. The mechanical strain, or the total strain minus the environmental strain, can be used to determine the drying shrinkage.

$$\boldsymbol{\varepsilon_{mechanical}} = (\boldsymbol{R_1} - \boldsymbol{R_0}) + \left((\boldsymbol{T_1} - \boldsymbol{T_0}) * (\boldsymbol{CF_{st}} - \boldsymbol{CF_c})\right) \quad \textbf{[2]}$$

where:

CFc: coefficient of thermal expansion of concrete (from laboratory tests)

The drying shrinkage at VW sensor 2 (1 in. above the bottom of the slab) is shown in Figure 2. Additional shrinkage plots are included in Appendix C. As shown in Figure 5, shrinkage is affected by temperature and relative humidity, with the greatest shrinkage occurring in the summer and the least in the winter.

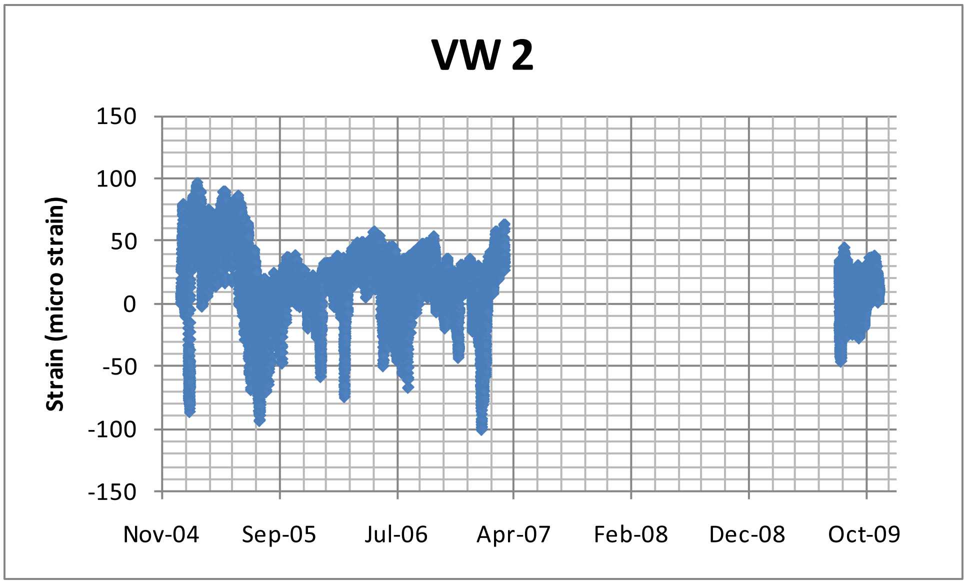

FIGURE 5 Shrinkage and bottom VW 2 sensor.

3.2 Joint Closure Temperatures

The joint closure temperature was found using the mechanical strain from Equation 2. The joint closure temperature was then determined by plotting the mechanical strain versus temperature as shown in Figure 6. When the joint closes, the slope of the strain temperature plot should change. The temperature at which the curve significantly changes slope is considered the joint closure temperature. Due to increased moisture contents in the spring, joint closure temperatures were analyzed for spring and summer separately. Temperatures in the fall and winter typically are not hot enough to cause joint closure therefore those seasons were left out.

The coefficient of thermal expansion for concrete is typically between 7.4×10^{-6} and 13×10^{-6} mm/mm/°C. The concrete containing Mesabi Select aggregates used in Cell 54 had an average coefficient of thermal expansion of 7.28×10^{-6} mm/mm/°C. As shown in Tables 8 and 9, the joints in Cell 54 typically locked up at lower temperatures than Cells 5, 8, and 10; three JPCP on the MnROAD Mainline.

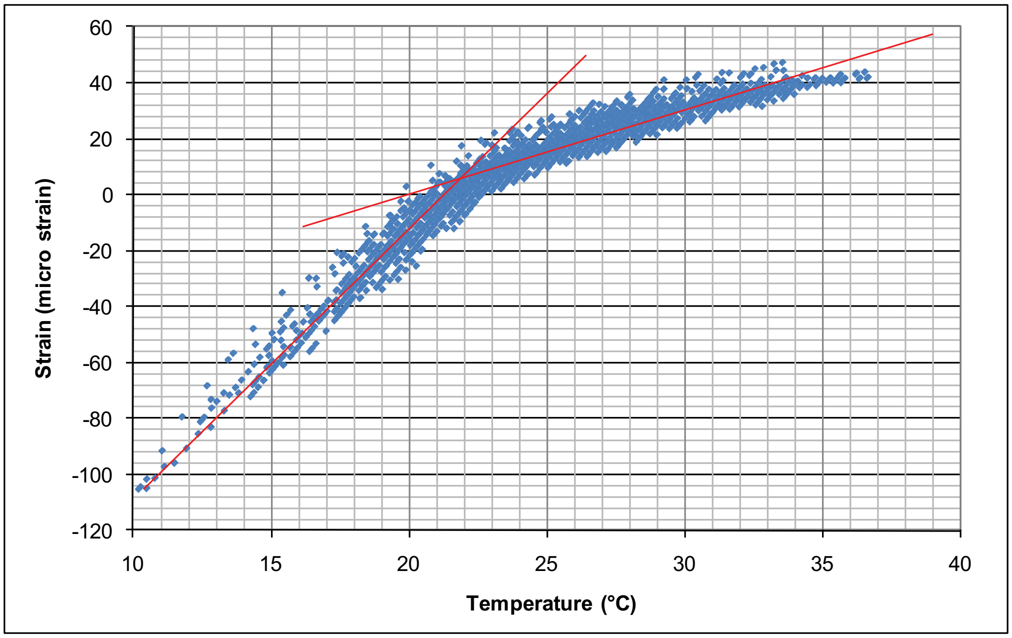

FIGURE 6 Joint closure temperature.

TABLE 8 Spring Joint Closure Temperatures

	Joint Closure Temperature (°C)										
	VW03	VW04	VW05	VW06	VW07	Cell 5	Cell 5	Cell 8	Cell 8	Cell 10	Cell 10
Age (months)	Top	Bottom	Top	Bottom	Top	Top	Bottom	Top	Bottom	Top	Bottom
6											
7	19	17	17	17	17						
8											
10										21	16
11										27	29
18											
19	22	26	26	27	23	19	15				
20						24	22				
22										20	
23								23	21	26	22

TABLE 9 Summer Joint Closure Temperatures

<table>
<tr><th></th><th colspan="11">Joint Closure Temperature (°C)</th></tr>
<tr><th></th><th>VW03</th><th>VW04</th><th>VW05</th><th>VW06</th><th>VW07</th><th>Cell 5</th><th>Cell 5</th><th>Cell 8</th><th>Cell 8</th><th>Cell 10</th><th>Cell 10</th></tr>
<tr><th>Age (months)</th><th>Top</th><th>Bottom</th><th>Top</th><th>Bottom</th><th>Top</th><th>Top</th><th>Bottom</th><th>Top</th><th>Bottom</th><th>Top</th><th>Bottom</th></tr>
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<tr><td>61</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>29</td><td>27</td><td>31</td><td>28</td></tr>
</table>

4 Summary and Conclusion

Mn/DOT constructed Cell 54 to study properties of Mesabi-Select as aggregate in concrete. This mineral aggregate, which contains lesser iron than the ore, was obtained from overburdens on the iron ore ledges in northern Minnesota. There is no record of a previous cell constructed to study the suitability of Mesabi-Select in concrete. This project constructed a 192-ft, jointed-plain-dowelled concrete pavement comprising two lanes of 12- by 15-ft slabs paved by slip-form construction process on October 22, 2004. The longitudinal joints were tied and unsealed. The inside lane has been loaded by the standard MnROAD 80-kip truck for over five years. Performance data was continuously obtained from embedded strain gauges, vibrating wires, moisture sensors, and thermocouples.

After five years:

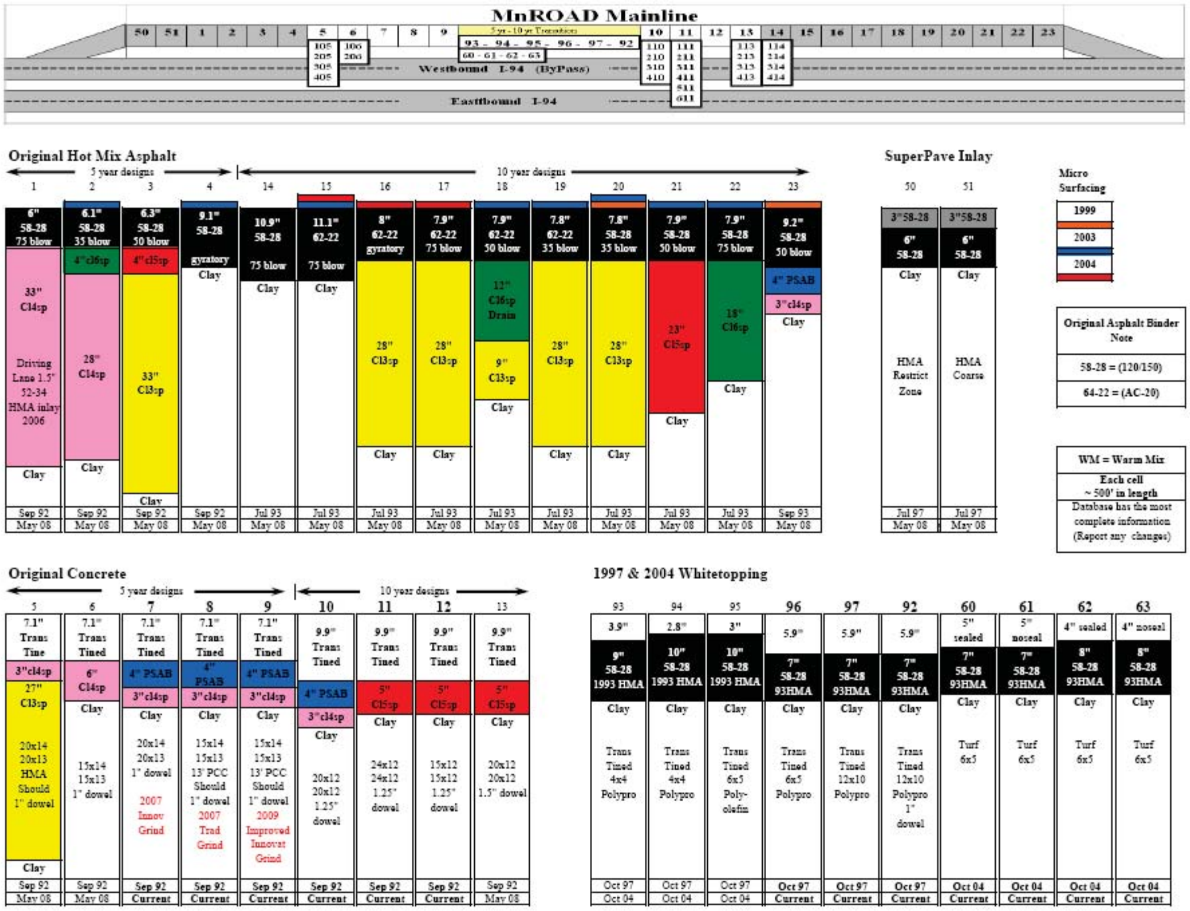
- Surface Distress: there are very few cracks of low severity. The types of distress found were spalling of transverse joints, longitudinal cracking, and transverse cracking. Very little joint faulting has occurred.
- Permeability: in-situ concrete surface permeability measurements indicate that the concrete is good quality.
- Friction: friction number with a smooth tire ranged from 29.1 to 42.5 and with a ribbed tire from 51.2 to 63.5.
- IRI: varies from 79.4 to 91.3 in/mi.
- The joint closure temperature, measured by vibrating wire strain gauges, was lower than that in other concrete test cells of similar design and thickness at MnROAD.
- FWD deflections at the surface and top of the base were of similar magnitude as in other doweled JPCP test cells of similar design.

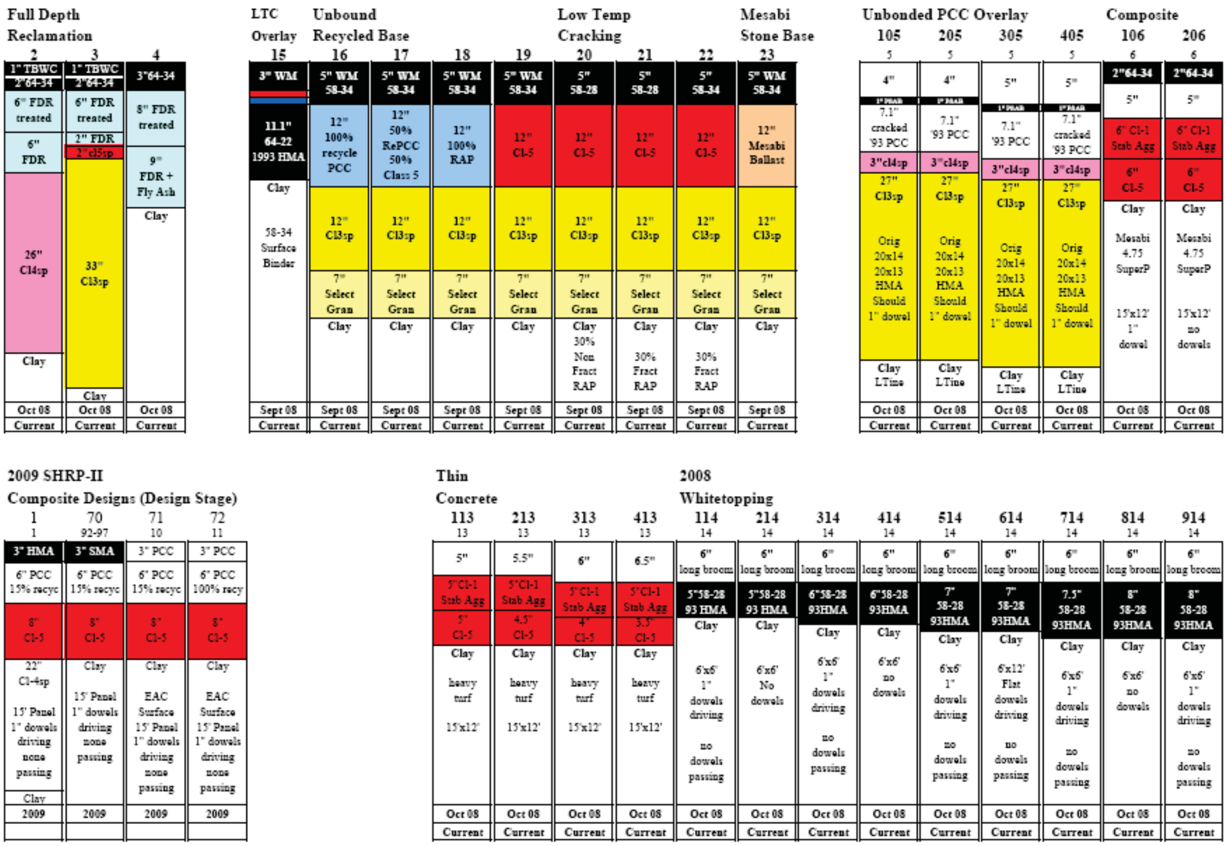
References

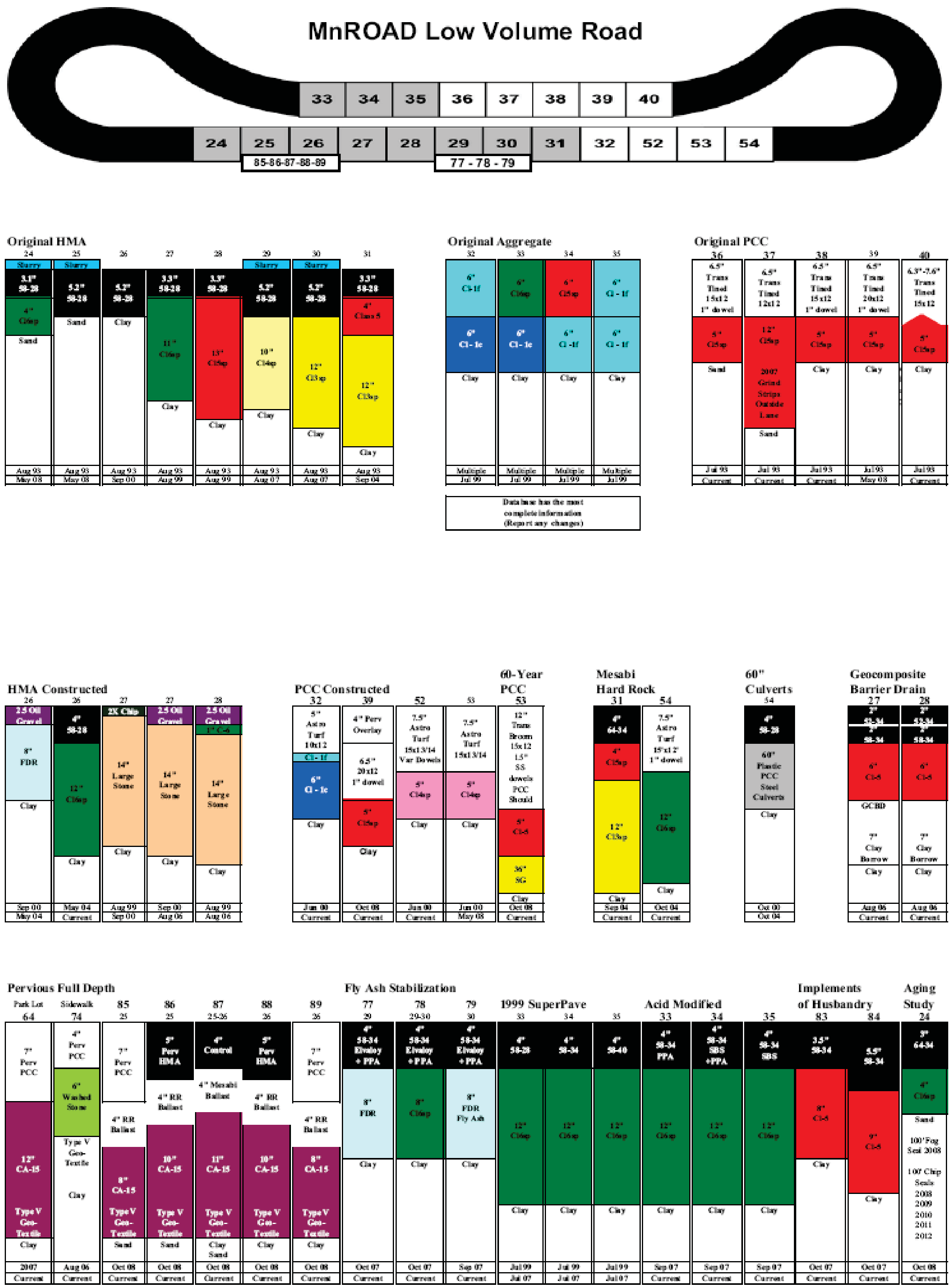
1 T. Burnham and A. Boubaa (2001). "A New Approach to Estimate the In-Situ Thermal Coefficient and Drying Shrinkage for Jointed Concrete Pavement," 7th International Conference on Concrete Pavements, Orlando, FL, September 9-13.

2 B. I. Izevbekhai and R. Rohne (2008). *MnROAD Cell 54: Cell Constructed With Mesabi-Select (Taconite-Overburden) Aggregate; Construction and Early Performance*, Report No. MN/RC 2008-18, Minnesota Department of Transportation, St. Paul, MN.

APPENDIX A
MnROAD Test Sections


MnROAD Mainline
Westbound I-94 (ByPass)
Eastbound I-94
Original Hot Mix Asphalt
5 year designs
10 year designs
SuperPave Inlay
Micro Surfacing
1999
2003
2004
Original Asphalt Binder Note
58-28 = (120/150)
64-22 = (AC-20)
WM = Warm Mix
Each cell ~ 500' in length
Database has the most complete information (Report any changes)
Original Concrete
1997 & 2004 Whitetopping


Full Depth Reclamation
2: 1" TBWC / 2"64-34 / 6" FDR treated / 6" FDR / 26" Cl4sp / Clay / Oct 08 / Current
3: 1" TBWC / 2"64-34 / 6" FDR treated / 2" FDR / 2" cl5sp / 33" Cl3sp / Clay / Oct 08 / Current
4: 3"64-34 / 8" FDR treated / 9" FDR + Fly Ash / Clay / Oct 08 / Current
LTC Overlay
15: 3" WM / 11.1" 64-22 1993 HMA / Clay / 58-34 Surface Binder / Sept 08 / Current
Unbound Recycled Base
16: 5" WM 58-34 / 12" 100% recycle PCC / 12" Cl3sp / 7" Select Gran / Clay / Sept 08 / Current
17: 5" WM 58-34 / 12" 50% RePCC 50% Class 5 / 12" Cl3sp / 7" Select Gran / Clay / Sept 08 / Current
18: 5" WM 58-34 / 12" 100% RAP / 12" Cl3sp / 7" Select Gran / Clay / Sept 08 / Current
19: 5" WM 58-34 / 12" Cl-5 / 12" Cl3sp / 7" Select Gran / Clay / Sept 08 / Current
Low Temp Cracking
20: 5" 58-28 / 12" Cl-5 / 12" Cl3sp / 7" Select Gran / Clay 30% Non Fract RAP / Sept 08 / Current
21: 5" 58-28 / 12" Cl-5 / 12" Cl3sp / 7" Select Gran / Clay 30% Fract RAP / Sept 08 / Current
22: 5" 58-34 / 12" Cl-5 / 12" Cl3sp / 7" Select Gran / Clay 30% Fract RAP / Sept 08 / Current
Mesabi Stone Base
23: 5" WM 58-34 / 12" Mesabi Ballast / 12" Cl3sp / 7" Select Gran / Clay / Sept 08 / Current
Unbonded PCC Overlay
105 5: 4" / 7.1" cracked '93 PCC / 3"cl4sp / 27" Cl3sp Orig 20x14 20x13 HMA Should 1" dowel / Clay LTine / Oct 08 / Current
205 5: 4" / 7.1" '93 PCC / 3"cl4sp / 27" Cl3sp Orig 20x14 20x13 HMA Should 1" dowel / Clay LTine / Oct 08 / Current
305 5: 5" / 7.1" '93 PCC / 3"cl4sp / 27" Cl3sp Orig 20x14 20x13 HMA Should 1" dowel / Clay LTine / Oct 08 / Current
405 5: 5" / 7.1" cracked '93 PCC / 3"cl4sp / 27" Cl3sp Orig 20x14 20x13 HMA Should 1" dowel / Clay LTine / Oct 08 / Current
Composite
106 6: 2"64-34 / 5" / 6" Cl-1 Stab Agg / 6" Cl-5 / Clay Mesabi 4.75 SuperP 15'x12' 1" dowel / Oct 08 / Current
206 6: 2"64-34 / 5" / 6" Cl-1 Stab Agg / 6" Cl-5 / Clay Mesabi 4.75 SuperP 15'x12' no dowels / Oct 08 / Current
2009 SHRP-II Composite Designs (Design Stage)
1 1: 3" HMA / 6" PCC 15% recyc / 8" Cl-5 / 22" Cl-4sp 15' Panel 1" dowels driving none passing / Clay / 2009
70 92-97: 3" SMA / 6" PCC 15% recyc / 8" Cl-5 / Clay 15' Panel 1" dowels driving none passing / 2009
71 10: 3" PCC / 6" PCC 15% recyc / 8" Cl-5 / Clay EAC Surface 15' Panel 1" dowels driving none passing / 2009
72 11: 3" PCC / 6" PCC 100% recy / 8" Cl-5 / Clay EAC Surface 15' Panel 1" dowels driving none passing / 2009
Thin Concrete
113 13: 5" / 5"Cl-1 Stab Agg / 5" Cl-5 / Clay heavy turf 15'x12' / Oct 08 / Current
213 13: 5.5" / 5"Cl-1 Stab Agg / 4.5" Cl-5 / Clay heavy turf 15'x12' / Oct 08 / Current
313 13: 6" / 5"Cl-1 Stab Agg / 4" Cl-5 / Clay heavy turf 15'x12' / Oct 08 / Current
413 13: 6.5" / 5"Cl-1 Stab Agg / 3.5" Cl-5 / Clay heavy turf 15'x12' / Oct 08 / Current
2008 Whitetopping
114 14: 6" long broom / 5"58-28 93 HMA / Clay 6'x6' 1" dowels driving no dowels passing / Oct 08 / Current
214 14: 6" long broom / 5"58-28 93 HMA / Clay 6'x6' No dowels / Oct 08 / Current
314 14: 6" long broom / 6"58-28 93HMA / Clay 6'x6' 1" dowels driving no dowels passing / Oct 08 / Current
414 14: 6" long broom / 6"58-28 93HMA / Clay 6'x6' no dowels / Oct 08 / Current
514 14: 6" long broom / 7" 58-28 93HMA / Clay 6'x6' 1" dowels driving no dowels passing / Oct 08 / Current
614 14: 6" long broom / 7" 58-28 93HMA / Clay 6'x12' Flat dowels driving no dowels passing / Oct 08 / Current
714 14: 6" long broom / 7.5" 58-28 93HMA / Clay 6'x6' 1" dowels driving no dowels passing / Oct 08 / Current
814 14: 6" long broom / 8" 58-28 93HMA / Clay 6'x6' no dowels / Oct 08 / Current
914 14: 6" long broom / 8" 58-28 93HMA / Clay 6'x6' 1" dowels driving no dowels passing / Oct 08 / Current


MnROAD Low Volume Road
33 34 35 36 37 38 39 40
24 25 26 27 28 29 30 31 32 52 53 54
85-86-87-88-89
77 - 78 - 79
Original HMA
Original Aggregate
Original PCC
Database has the most complete information (Report any changes)
HMA Constructed
PCC Constructed
60-Year PCC
Mesabi Hard Rock
60" Culverts
Geocomposite Barrier Drain
Pervious Full Depth
Fly Ash Stabilization
1999 SuperPave
Acid Modified
Implements of Husbandry
Aging Study

APPENDIX B
MnROAD Grip Tester Runs

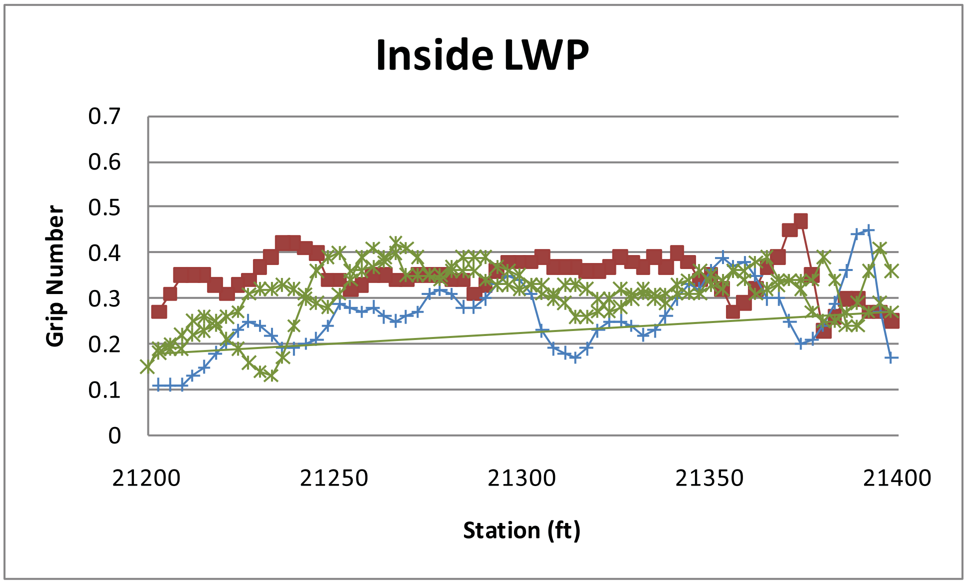


FIGURE B1 Inside lane left wheel path grip number.

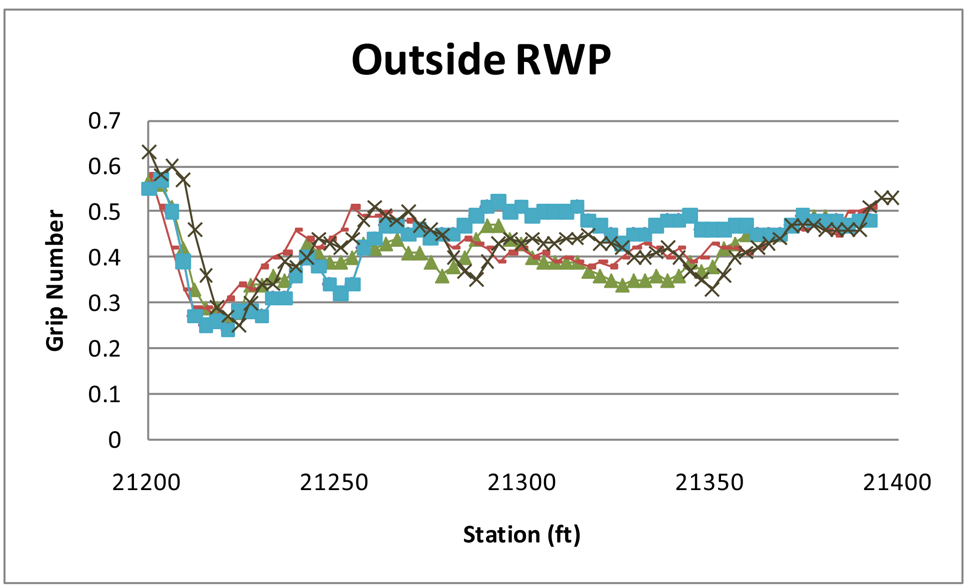


FIGURE B2 Outside lane right wheel path grip number.

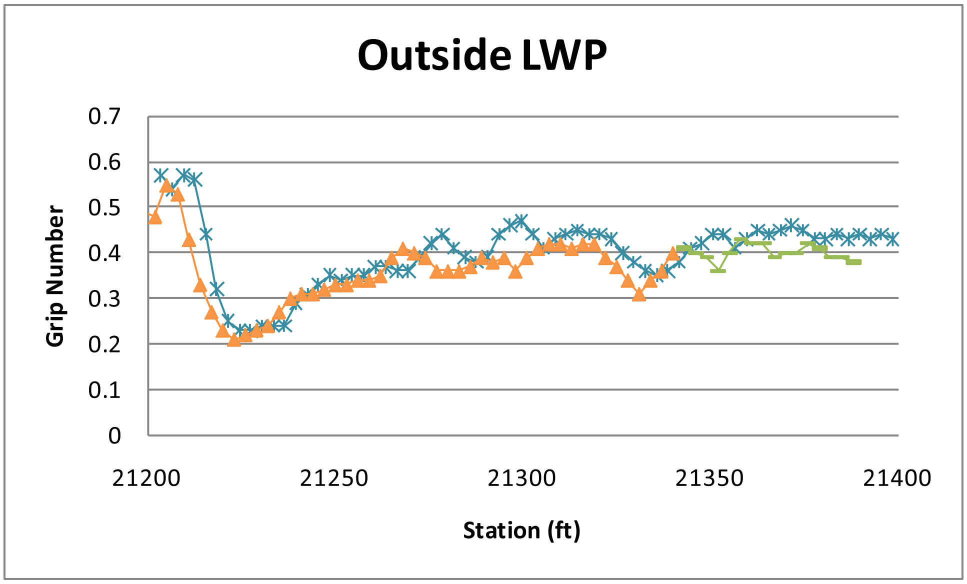


FIGURE B3 Outside lane left wheel path grip number.

APPENDIX C
Shrinkage Plots

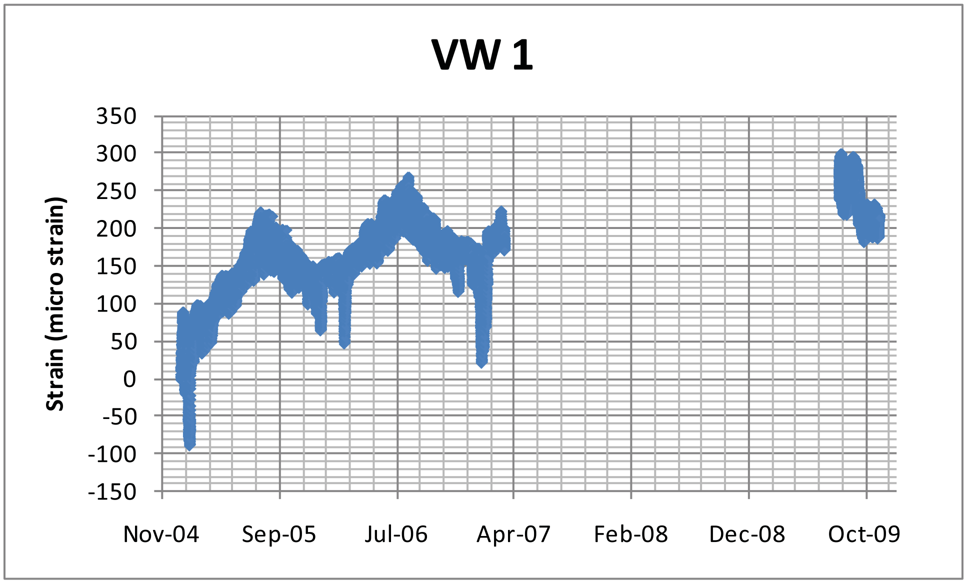


Figure C1 Shrinkage at top VW 1 sensor.

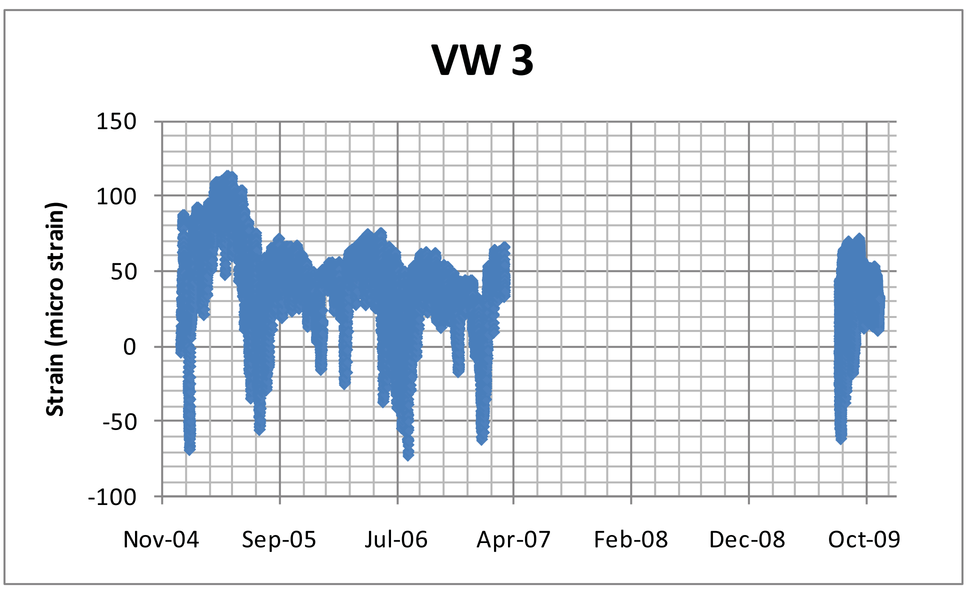


Figure C2 Shrinkage at top VW 3 sensor.

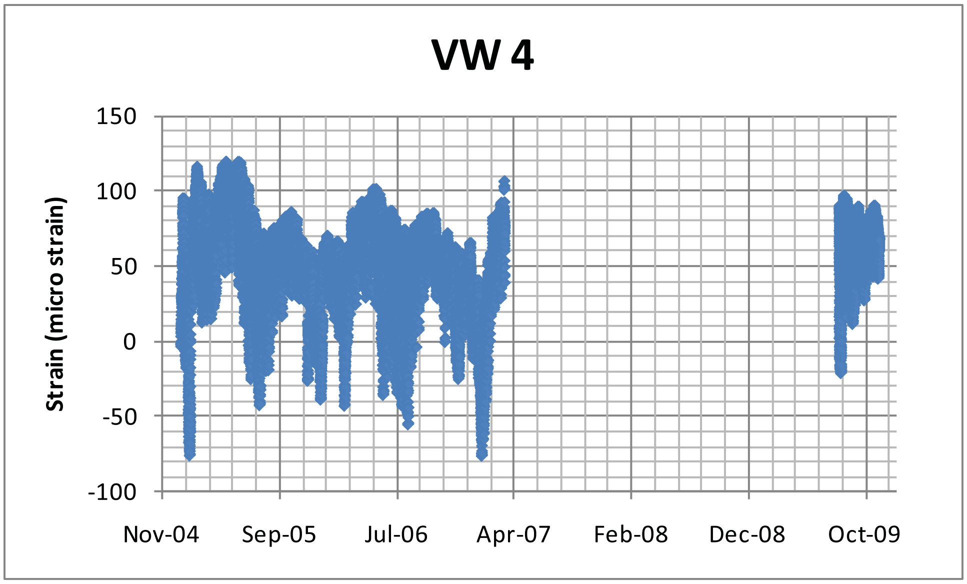


Figure C3 Shrinkage at bottom VW 4 sensor.

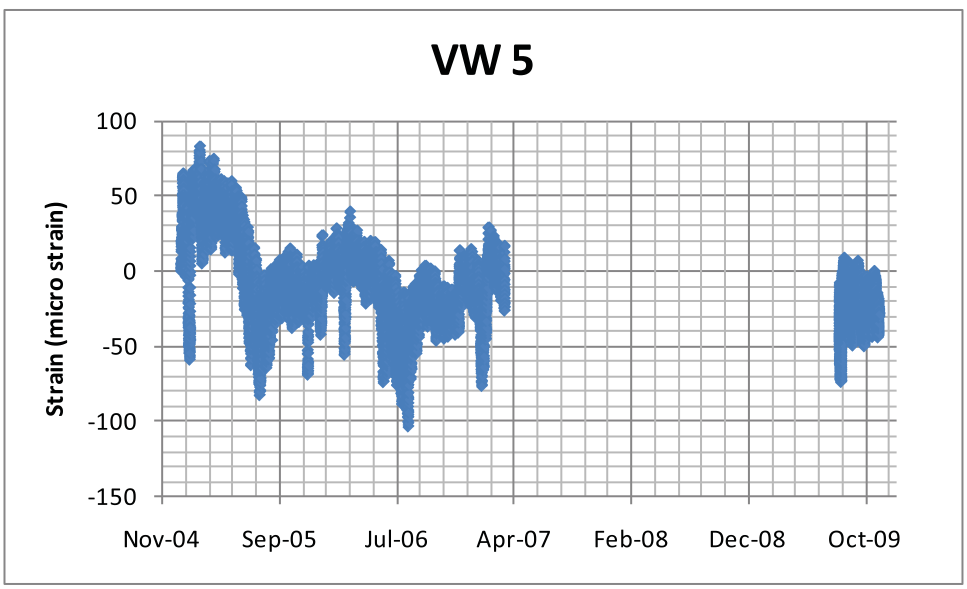


Figure C4 Shrinkage at top VW 5 sensor.

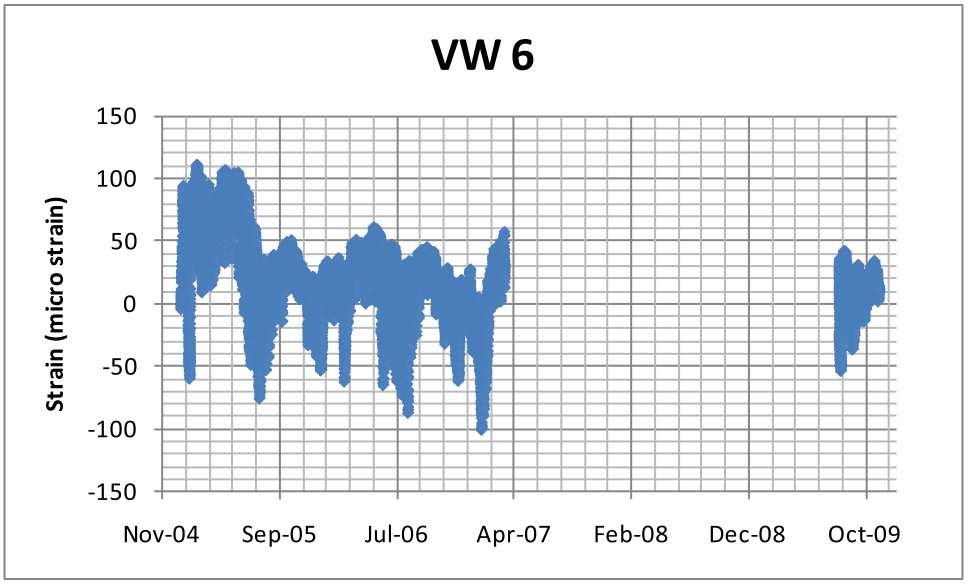


Figure C5 Shrinkage at bottom VW 6 sensor.

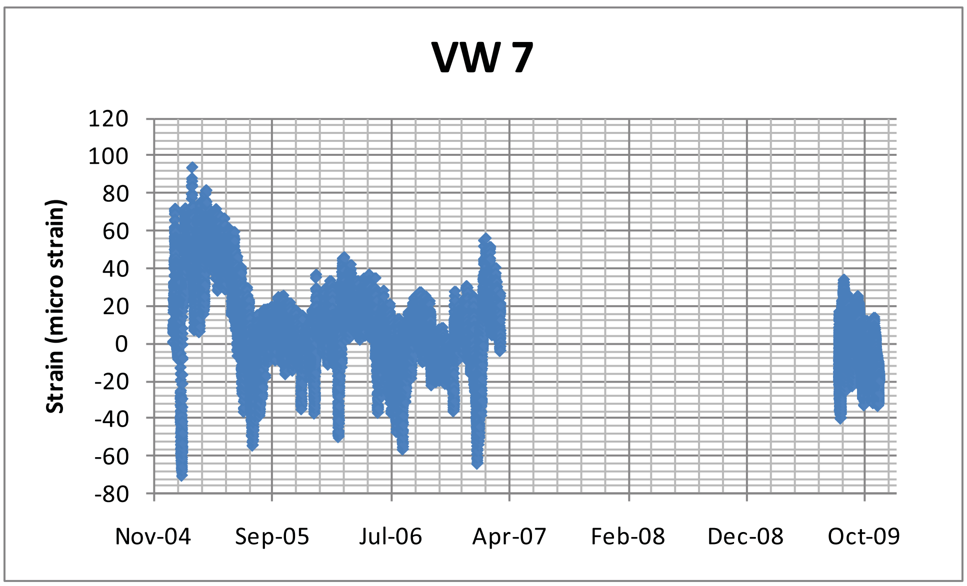


Figure C6 Shrinkage at top VW 7 sensor.

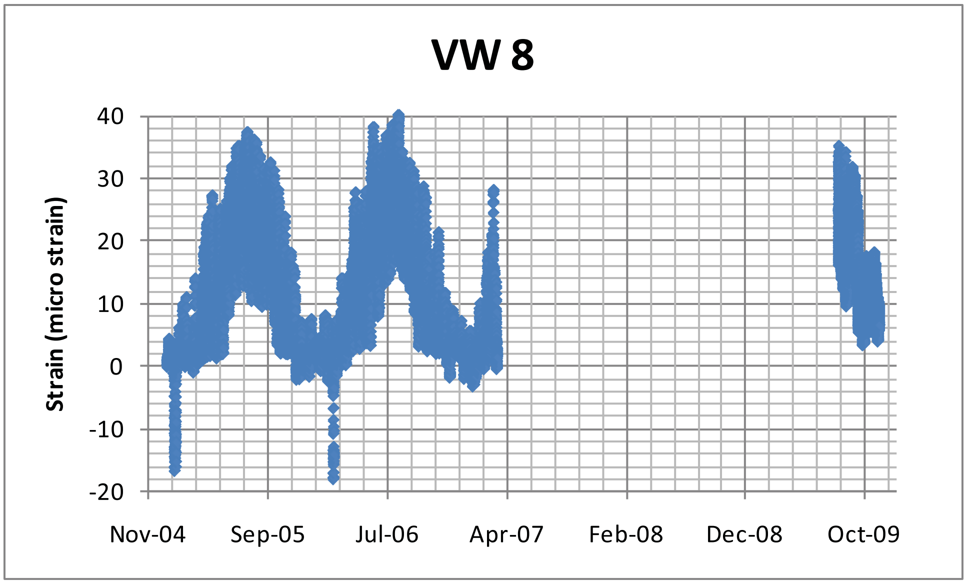


Figure C7 Shrinkage at bottom VW 8 sensor.